

HETEROGENEOUS FELDSPARS IN THE MID-TRIASSIC VOLCANIC ROCKS OF THE DOLOMITES

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ABSTRACT

Feldspar phenocrysts from effusive rocks of the Dolomites (Southern Alps) show coarse, concentric zonation of plagioclase and K-feldspar. Electron-microprobe analyses of the various zones within any one phenocryst indicate atypical compositions for the coexisting phases. The plagioclases range from labradorite to andesine (An 45–70%); the K-feldspars have very high K contents (Or 95–96%) and correspondingly very low Ab contents (3–4%). A growth model for such phenocrysts is difficult to establish. The proposed mechanism is that of a primary sequential crystallization followed by successive modifications occurring during the complex postmagmatic history of the rock.

these filled the basins between the Anisian and the Ladinian carbonate formations. The emplacement of two intrusive complexes as ring dykes of monzonitic and granitic rocks around a volcanic system at Predazzo, and of pyroxenitic through monzonitic rocks at Monzoni, is also related to this activity.

The composition of these igneous rocks in many respects suggests a shoshonitic series (Rossi *et al.* 1976, Castellarin *et al.* 1977, Calanchi *et al.* 1978). Their petrochemistry, however, is rather complex, owing both to the lack of differentiation in the volcanic units (important only in small intrusive bodies), and to the common and often remarkable postmag-

SOMMAIRE

Les phénocristaux de feldspath des roches éruptives des Dolomites (Alpes Méridionales) montrent une zonation concentrique grossière de plagioclase et de feldspath potassique. Les analyses à la microsonde des zones d'un même phénocrystal révèlent des compositions atypiques des phases coexistantes. Les plagioclases varient du labrador à l'andésine (An 45–70), tandis que les zones de feldspath potassique ont une teneur très élevée en potassium (Or 95–96) et par suite très basse en sodium (Ab 3–4). Un schéma de croissance qui expliquerait de tels phénocristaux n'est pas facile à établir. Nous proposons comme mécanisme une cristallisation primaire en stades successifs, suivie de modifications postmagmatiques qui survinrent durant l'évolution complexe de la roche.

(Traduit par la Rédaction)

INTRODUCTION

During the interval between the Upper Ladinian and Lower Carnian of the Mid-Triassic, extensive magmatic activity occurred in the southern Alps, particularly in the area of the Dolomites, leading to the emplacement of large volcanic bodies, mostly underwater;

TABLE 1. WHOLE-ROCK WET CHEMICAL ANALYSES OF X45 AND $\Sigma 5$ COMPARED TO A MORE TYPICAL COMPOSITION (X)

	X45	$\Sigma 5$	X
SiO ₂	51.57	47.58	49.46
TiO ₂	0.87	0.99	1.13
Al ₂ O ₃	21.35	15.57	17.39
Fe ₂ O ₃	3.49	6.96	5.39
FeO	3.08	3.61	4.19
MnO	0.06	0.11	0.17
MgO	3.37	6.32	4.95
CaO	3.74	6.83	8.55
Na ₂ O	4.00	2.00	2.66
K ₂ O	4.85	4.57	2.30
P ₂ O ₅	0.37	0.37	0.35
H ₂ O-	0.94	1.58	0.94
H ₂ O+	2.79	2.71	2.44
CO ₂	-	.59	-
Totals	100.48	99.79	99.92

X45: Pillow lava from "Monte Migogn".

$\Sigma 5$: Lava flow from "Alpe di Stusi".

X: Shoshonitic basalt; a representative sample of the Middle Triassic volcanism of Southern Alps.

matic mineral transformations that the minerals have undergone, most likely as a result of the subaqueous environment of their emplacement. Such transformations have affected mostly the plagioclases, which may be completely transformed into albite, whereas the pyroxenes, of the augite-salite type, are almost always unaffected. The albitization of these rocks proceeds as stated by Vallance (1969), with a general enrichment in Na_2O and loss of CaO relative to the unaltered types. However, it is not our aim here to discuss the complex problem of spilitization or albitization.

In a few samples, an abnormal enrichment in K_2O has been observed which cannot be accounted for by the normal process of differentiation. This paper reports the study of two such K-rich specimens; under the microscope, both show very interesting textural rela-

tionships involving the feldspars. Our aim in the present work is primarily to report analytical data bearing on these phases in the two samples. A more complete study of the genesis, chemistry and structural relationships is planned on a larger number of samples with analogous features, possibly including other occurrences of the same phenomenon.

The two specimens considered are labeled X45 and $\Sigma 5$. Whole-rock chemical analyses are reported in Table 1 together with one analysis of the most common rock-type (X).

PETROGRAPHY

The two specimens selected represent separate flows. One (X45) comes from an exposure of a pillow lava near Mt. "Migogn" in the

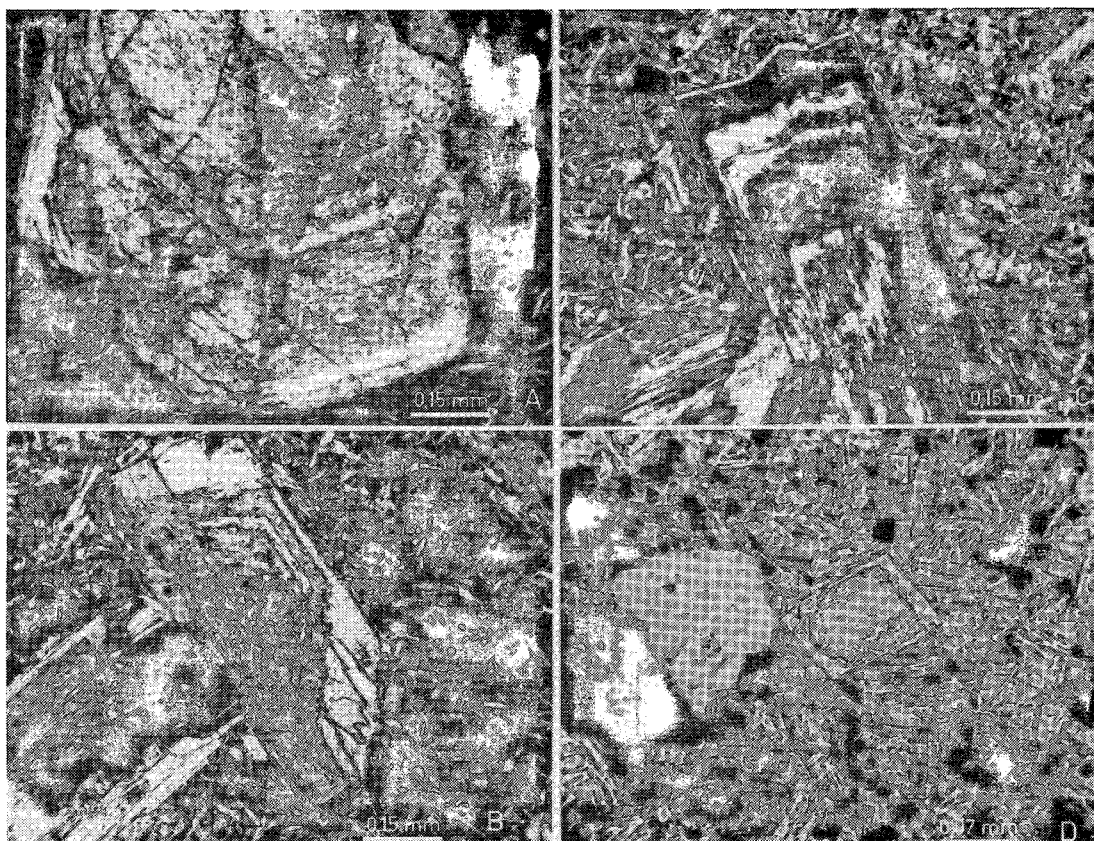


FIG. 1. A) K-feldspar zoning in plagioclase phenocryst, crossed polarizers, sample $\Sigma 5$; B) K-feldspar core and inner rim within phenocryst, crossed polarizers, sample $\Sigma 5$; C) K-feldspar (dark) and plagioclase (light) alternations, crossed polarizers, sample X45; D) microphenocrysts of K-feldspar with thin plagioclase outer rim, plane polarized light, sample X45.

upper Cordevole valley (Belluno); stratigraphically, it occurs above the Marmolada conglomerate and is therefore associated with a late volcanic event (Lower Carnian). The second occurrence ($\Sigma 5$) has the appearance of a subaerial lava flow; it is located west of the Alpe di Tires (Bolzano) and is probably also related to volcanic activity of the lower Carnian. Microscopic examination of both rocks reveals a porphyritic texture. Sample X45 contains almost exclusively plagioclase as phenocrysts, embedded in a groundmass of feldspathic microlites, whereas $\Sigma 5$ contains phenocrysts of plagioclase, clinopyroxene and olivine (partly replaced by calcite, iron oxides and hydroxides) embedded in a feldspathic groundmass.

The plagioclase phenocrysts in both samples have average dimensions of approximately 2–3 mm, with slight alteration to sericite; in some cases, the phenocrysts also contain small grains of opaque minerals. The main characteristic of these phenocrysts is the presence of K-feldspar distributed within them in various patterns. The most common variety consists of a few regular and nearly continuous concentric zones of K-feldspar 10 to 20 μm wide that develop within a phenocryst parallel to its margins (Fig. 1A, B, C, D). There are up to four K-feldspar zones in the same crystal, always with a common optical orientation. If the plagioclase is twinned, so is the K-feldspar. In other cases the K-feldspar constitutes the core of phenocrysts; the core zone, up to 60

μm across, is associated with small alternating rims of plagioclase towards the border. Complete variation between the two extreme cases has been observed.

Individual plagioclase phenocrysts containing such K-feldspar zones have decreasing An contents from core to rim despite the presence of intervening K-feldspar layers (Table 2). Typical compositions range from about 65% An for the inner plagioclase to about 55% An for the outer plagioclase. The outermost rim of the phenocrysts is always very fresh plagioclase, never K-feldspar.

K-feldspar can also be found distributed in small patches within the plagioclase phenocrysts, apparently without preferred orientation. In such cases the K-feldspar may constitute up to half the volume of the phenocrysts. The same associations are present in the microlites of the groundmass; there, one most commonly observes a K-feldspar core with only one rim of plagioclase (Fig. 1D); occasionally, one finds a plagioclase core rimmed by K-feldspar.

EXPERIMENTAL

Electron microprobe work was carried out in the wavelength-dispersive mode on a fully automated ARL-SEMQ instrument operated at 15 kV and 0.15–0.20 μA beam current, using a focused beam of approximately 1 μm diameter. Quantitative analyses were performed at several points for several representative feldspar crystals in thin sections of the two rock types, with counting times of 2, 20 and 2 seconds for high background, peak and low background, respectively. On-line data reduction was based on the Ziebold & Ogilvie (1964) method by the use of Bence & Albee (1968) and Albee & Ray (1970) correction factors. Synthetic plagioclase glass of composition An 100, natural albite, microcline and olivine were used as standards. Scanning X-ray micrographs were obtained with very long exposure times for maximum resolution and detail.

DISCUSSION OF THE RESULTS

Typical compositions of the feldspar zones are reported in Table 2 as averages of four to nine point-analyses for each feldspar composition. The composition of each type of feldspar ranges within $\pm 5\%$ of the percentages of the major elements and within $\pm 20\%$ for the elements present in concentrations below 10% in weight percent oxide. The

TABLE 2. AVERAGE OXIDE COMPOSITIONS AND ATOMIC RATIOS OF THE THREE REPRESENTATIVE FELDSPAR ZONES FOR EACH ROCK

	X45			$\Sigma 5$		
	Inner Plag.	Outer Plag.	K-feldspar	Inner Plag.	Outer Plag.	K-feldspar
SiO ₂	53.6	56.6	65.4	49.3	51.3	64.1
Al ₂ O ₃	28.5	26.3	17.4	30.6	29.6	18.8
FeO*	0.6	0.9	0.1	0.9	1.0	0.3
MgO	0.1	0.1	0.0	0.2	0.2	0.3
SrO	0.3	N.D.	0.0	N.D.	N.D.	N.D.
BaO	0.0	N.D.	0.0	N.D.	N.D.	N.D.
CaO	12.1	9.5	0.0	14.7	13.4	0.1
Na ₂ O	4.4	5.1	0.3	2.9	3.4	0.4
K ₂ O	0.6	1.7	16.4	0.5	0.6	15.9
Total	100.2	100.2	99.6	99.1	99.5	99.9
Number of Cations (O = 8)						
Si	2.4	2.6	3.0	2.3	2.4	3.0
Al	1.5	1.4	1.0	1.7	1.6	1.0
Ca	0.6	0.5	0.0	0.7	0.7	0.0
Na	0.4	0.4	0.0	0.3	0.3	0.0
K	0.0	0.1	1.0	0.0	0.0	0.9

* Total Iron calculated as FeO.

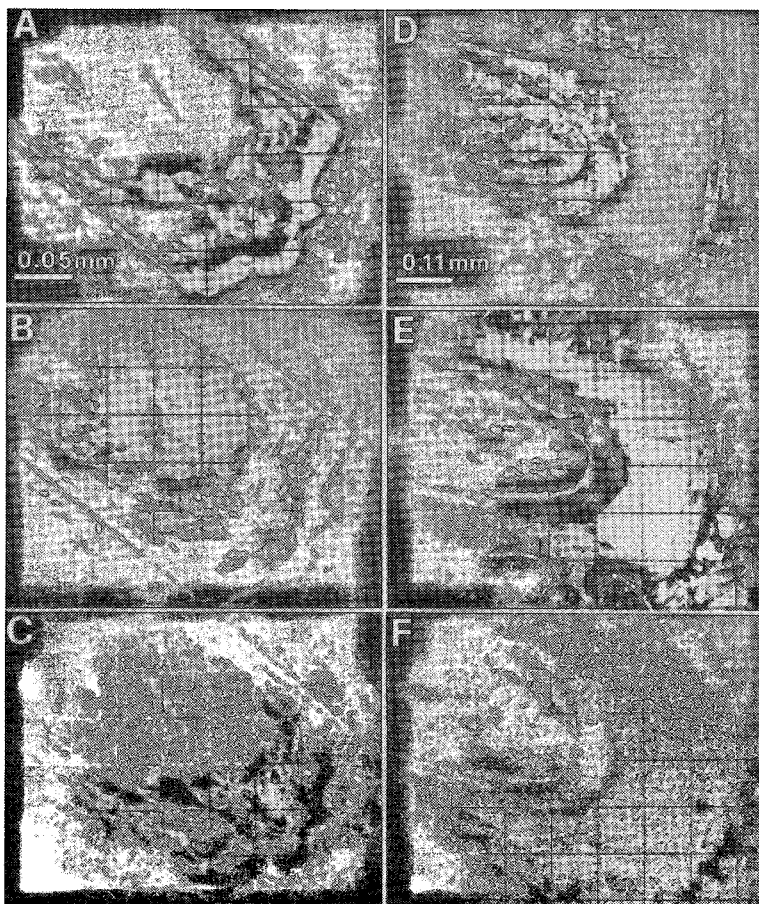


FIG. 2. A), B) and C): X-ray $K\alpha$ maps of K, Ca and Na radiations, respectively, in sample X45; D), E) and F): analogous X-ray maps, sample $\Sigma 5$.

elemental distribution of K, Ca and Na in the phenocrysts is shown in the X-ray micrographs of Figure 2.

The intimate association of feldspar phases may be explained by one or more of the following mechanisms (Smith 1974): (1) subsolidus exsolution, (2) sequential growth, (3) replacement. In our case, the regularity of the K-feldspar zones and their remarkable compositional homogeneity suggest that the first process is rather unlikely. The second mechanism proposed, the sequential growth of the feldspar phases, would seem, from the distribution of the phases, to offer a more likely explanation. However, the composition of the K-feldspar zones differs greatly from what one might expect in phenocrysts of effusive rocks. The Or contents of the K-feldspars, almost constant at 95–96%, are distinctly different

TABLE 3. COMPOSITIONS OF THE POINTS REPORTED IN FIGURE 3

Points	1	2	3	4	5	6	7	8	9	10	11	12
SiO ₂	53.3	65.0	65.3	64.8	63.8	68.3	68.7	55.1	54.6	55.9	55.9	58.0
Al ₂ O ₃	29.0	17.9	17.7	17.9	17.9	18.7	18.4	26.1	26.5	27.0	26.1	25.5
FeO [†]	0.0	0.1	0.2	0.2	0.3	0.4	0.2	0.7	0.7	0.9	1.0	0.8
MgO	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
CaO	12.7	0.0	0.0	0.0	0.1	0.1	0.0	9.8	11.0	10.3	8.5	8.9
Na ₂ O	4.0	0.4	0.1	0.1	0.8	7.1	1.3	4.4	4.7	4.9	4.9	5.6
K ₂ O	0.6	15.9	16.2	16.4	14.5	6.0	10.4	1.2	1.0	1.7	2.4	1.8
Totals	99.7	99.3	99.5	99.4	97.4	100.6	99.0	97.4	98.6	100.8	99.2	100.7

† Total Iron calculated as FeO.

Note: All point-analyses taken at fixed spatial intervals. Compositions that are not in full agreement with Figure 3, are probably due to alteration, grain borders not parallel to the beam, surface topography, etc.

from those noted by Lofgren & Gooley (1977) for synthetic phases. They found compositions

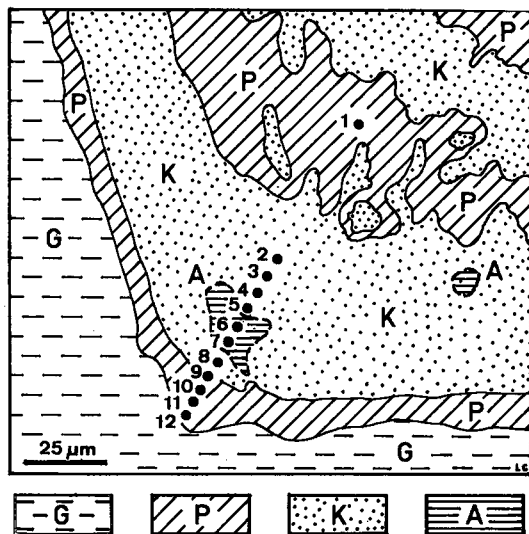


Fig. 3. Scheme of compositional zoning and points analyzed as reported in Table 3. G: groundmass; P: plagioclase zones; K: K-feldspar zones; A: patches with anorthoclase composition. Numbers refer to analyses in Table 3, dots mark beam position and approximate spot-size for each point analysis; sample X45.

between Or 75 and Or 55. Therefore, with the compositions we found, the hypothesis of sequential growth cannot be taken into consideration unless one admits subsequent phenomena of unmixing and removal of sodium from alkali feldspar to give K-rich sanidine.

A notable contribution to such a hypothesis is given, in some cases, by the occurrence of very small and irregular patches of "anorthoclase" composition (Ab~63, Or~36) (Table 3, Fig. 3, point 6) within the pure K-feldspar zones and the fairly common existence of dif-

TABLE 4. AVERAGE SELECTED COMPOSITIONS OCCURRING WITHIN THE MICROLITES SHOWING K-FELDSPARS DIFFERENT FROM THOSE OF THE PHENOCRYSTS.*

	K-Feldspar	K-Feldspar	Inner Plag.	Outer Plag.
SiO ₂	64.4	65.4	50.6	51.0
Al ₂ O ₃	20.7	19.2	30.9	31.7
FeO	0.4	0.4	1.0	0.9
MgO	0.0	0.1	0.1	0.2
CaO	1.3	0.8	12.8	13.6
Na ₂ O	3.9	3.7	3.1	3.5
K ₂ O	10.0	10.3	0.6	0.6
Totals	100.7	99.9	99.1	101.5

* Analyses of very small grains (20-30 µm²).

ferent compositions of the K-feldspars (Table 4) with approximately Or 60, Ab 35, An 5 in the microphenocrysts and microlites of the groundmass. Our degree of confidence associated with the analyses of Table 3 and 4 is much less than that of the analyses of Table 2 (see notes at bottom of tables); for this reason, atomic ratios are not reported. Nevertheless, these analyses represent quantitative measurements of the spatial-chemical relationship between phases. Such compositions could represent the product of primary crystallization and/or initial phases of a transformation that would have involved the phenocrysts more than the microlites of the groundmass. The composition of the plagioclase is nearly the same for both the phenocrysts and the microlites of the groundmass.

The sharp separation between the phases in contact and the continuity and shape of the zones, together with their reasonable homogeneity, favor a sequential crystallization, clearly dominated by a K-feldspar composition for some period, and then by a plagioclase. This mechanism could develop in response to the variations in water pressure inside the magma chamber as a result of the complex dynamics of the effusive activity. Two phases could thus be generated: a plagioclase such as the one observed and a potassic feldspar that must have been richer in Na than that presently found.

The third hypothesis, that of a metasomatic origin, could explain the K-feldspar compositions, although the regular, continuous and repetitive concentric zones, commonly in optical continuity with the plagioclase zones, are quite difficult to explain in this way. With this hypothesis, there exists one additional problem: the constant presence, in the outermost border, of plagioclase, never K-feldspar.

In conclusion, we believe that no single mechanism can be firmly supported. However, we prefer a hypothesis of primary sequential crystallization of the K-feldspar and plagioclase, with local modifications due to the possible ion exchange by solid-state reactions during the complex subsolidus history of the rocks.

ACKNOWLEDGEMENTS

Thanks are due to Professor R. B. Ferguson for critical reading of the manuscript. Electron microprobe work at the "Istituto di Mineralogia e Petrologia, Università di Modena", was made possible by the financial support of the "Consiglio Nazionale delle Ricerche" of Italy.

REFERENCES

- ALBEE, A. L. & RAY, L. (1970): Correction factors for electron probe microanalysis of silicates, oxides, carbonates, phosphates and sulphates. *Anal. Chem.* **42**, 1408-1414.
- BENCE, A. E. & ALBEE, A. L. (1968): Empirical correction factors for the electron microanalysis of silicates and oxides. *J. Geol.* **76**, 382-403.
- CALANCHI, N., LUCCHINI, F. & ROSSI, P. L. (1978): The volcanic rocks from the Mount Agnello area (Fiemme Valley, Italy): a contribution to the knowledge of the Mid-Triassic magmatism of the Southern Alps. *Tschermaks Mineral. Petrog. Mitt.* **25**, 131-143.
- CASTELLARIN, A., ROSSI, P. L., SIMBOLI, G., SOMMAVILLA, E. & DE LUCA, A. (1977): Dati geologici e petrografici sul gruppo del Buffaure. *Mineral. Petrog. Acta* **21**, 165-187.
- LOFGREN, G. E. & GOOLEY, R. (1977): Simultaneous crystallization of feldspar intergrowths from the melt. *Amer. Mineral.* **62**, 217-228.
- ROSSI, P. L., SIMBOLI, G. & VIEL, G. (1976): Significato paleogeografico e magmatico-tettonico della serie vulcanica, vulcano-clastica ladinica superiore del Monte Civetta. *Soc. Geol. Ital. Boll.* **95**, 433-458.
- SMITH, J. V. (1974): *Feldspar Minerals. 2. Chemical and Textural Properties*. Springer-Verlag, Berlin.
- VALLANCE, T. G. (1969): Spilites again: some consequences of the degradation of basalts. *Proc. Linn. Soc. N.S. Wales* **94**, 8-51.
- ZIEBOLD, T. O. & OGILVIE, R. E. (1964): An empirical method for electron microanalysis. *Anal. Chem.* **36**, 322-327.

Received January 1978; revised manuscript accepted November 1978.